Network performance of autonomous vehicles at low market shares

Papu Carrone, Andrea Vanesa; Rich, Jeppe

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NETWORK PERFORMANCE OF AVs AT LOW MARKET SHARES

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Andrea Papu Carrone
Jeppe Rich
TRANSPORT MODELLING

DTU Management Engineering
Department of Management Engineering

Outline

- Motivation
- Model formulation
- Experiment setup
- Simulation framework
- Case Study: Results
- How / What should we plan?
- Conclusions

Motivation (I)

- AVs conceived to:
  - Increase safety
  - Reduce pollution
  - Optimize inefficient use of infrastructure
  - Reduce congestion

Will it be possible?

- Technological advances in sensing technology, wireless communications and data processing.
- AVs already prototyped, car manufacturers working towards deployment.

Motivation (II)

MICROSCOPIC BEHAVIOR OF TRAFFIC

- Will AVs penetration to the market improve capacity and traffic flow?
- Is this improvement proportional to the % AVs?
  or, will AVs smooth traffic flow even at low rates of penetration?

- For 2050: 7 – 61% trips performed in AVs (Milakis et al.,2016)

Mixed traffic environment (regular cars + AVs)

Model formulation

IIDM: Improved Intelligent Driver Model

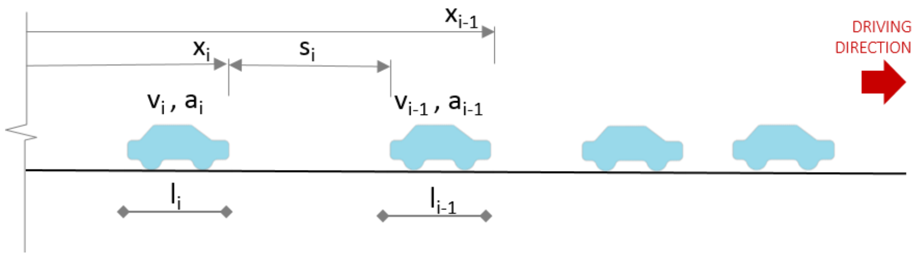
$$z_{ji} = \frac{DesS(v_{(j-1)i}, \Delta v_{(j-1)i})}{s_{(j-r_i)i}}$$

- if $v \leq v_0$

$$a_{free_{ji}} = A \cdot \left[1 - \left(\frac{v_{(j-r_i)i}}{v_{0i}}\right)^{\delta}\right], \qquad a_{ji} = \begin{cases} A \cdot [1 - z_{ji}^2] & z_{ji} \geq 1 \\ a_{free_{ji}} \cdot [1 - z_{ji}^{(2 \cdot A)/a_{free_{ji}}}] & z_{ji} < 1 \end{cases}$$

- if $v > v_0$

$$a_{free_{ji}} = -B \cdot \left[1 - \left(\frac{v_{0i}}{v_{(j-r_i)i}}\right)^{A \cdot \delta / B}\right], \quad a_{ji} = \begin{cases} a_{free_{ji}} + A \cdot \left[1 - z_{ji}^2\right] & z_{ji} \geq 1 \\ a_{free_{ji}} & z_{ji} < 1 \end{cases}$$



Cars — **Stochastic IIDM**

- $A = 3\ m/s^2$
- $B = 1.67\ m/s^2$
- $B_{max} = 7.5\ m/s^2$
- $S_0 = 2$ m
- T =1.5 s
- $\delta = 4$
- v_0 = norm(30.56;3.5^2) m/s
- r_i = norm(0.5;0.1^2) s

AVs — **Deterministic IIDM**

- $A = 3\ m/s^2$
- $B = 1.67\ m/s^2$
- $B_{max} = 7.5\ m/s^2$
- $S_0 = 2$ m
- **T = 1 s**
- $\delta = 4$
- v_0 = **30.56 m/s**
- $r_i = 0$ s

Parameters:

A = maximum acceleration

B = comfortable deceleration

B_{max} = maximum deceleration

s_0 = standstill safe gap

T = speed dependent safe gap

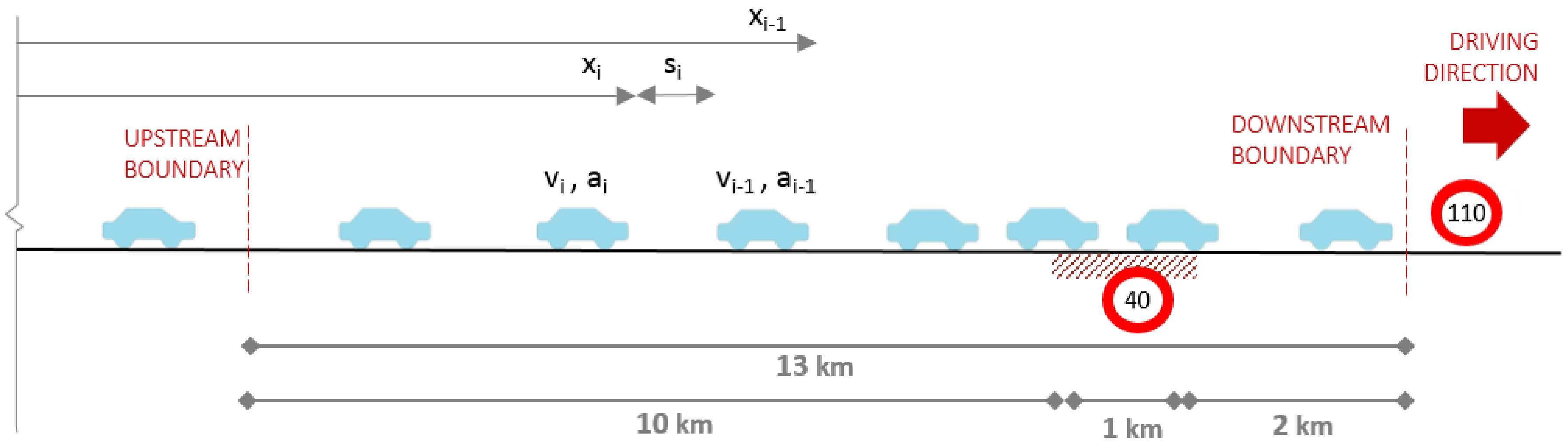
δ = IDM parameter

v_0 = desired speed

r_i = reaction time

Experiment setup

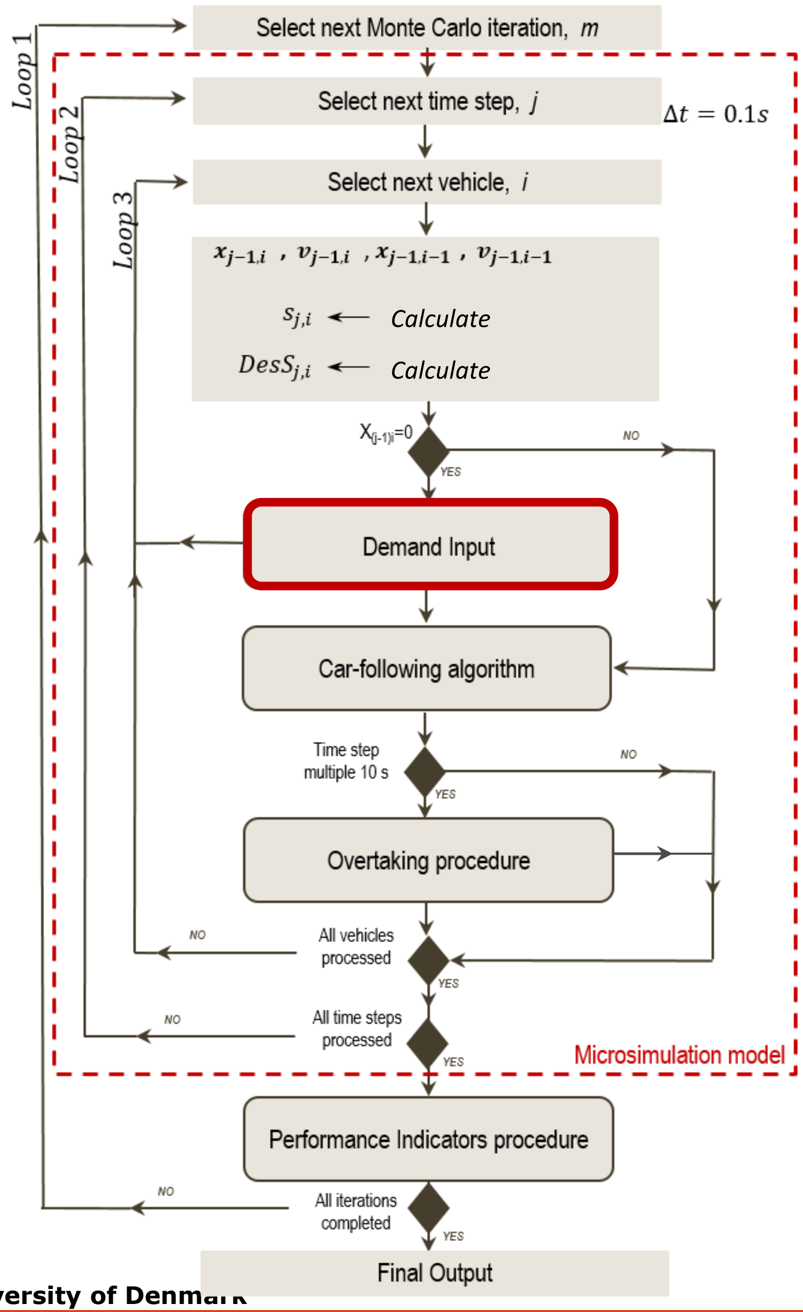
- Congested motorway performance

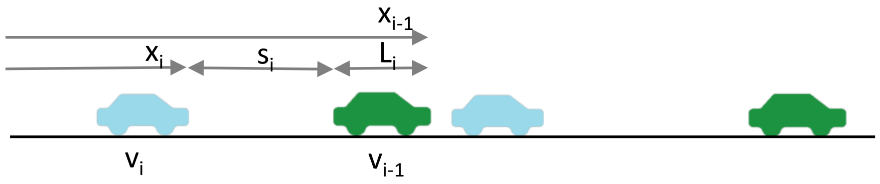


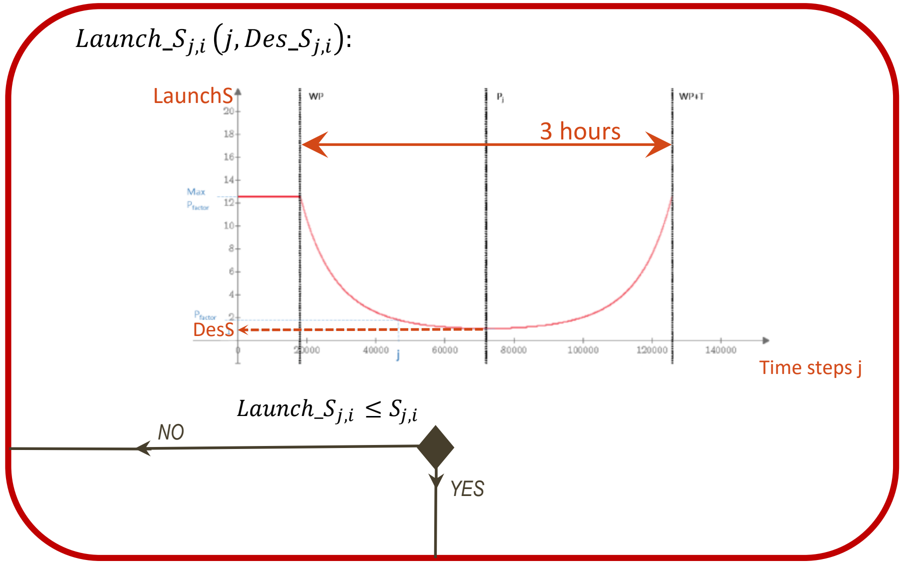
Stochastic IIDM

Deterministic IIDM

Simulation Framework







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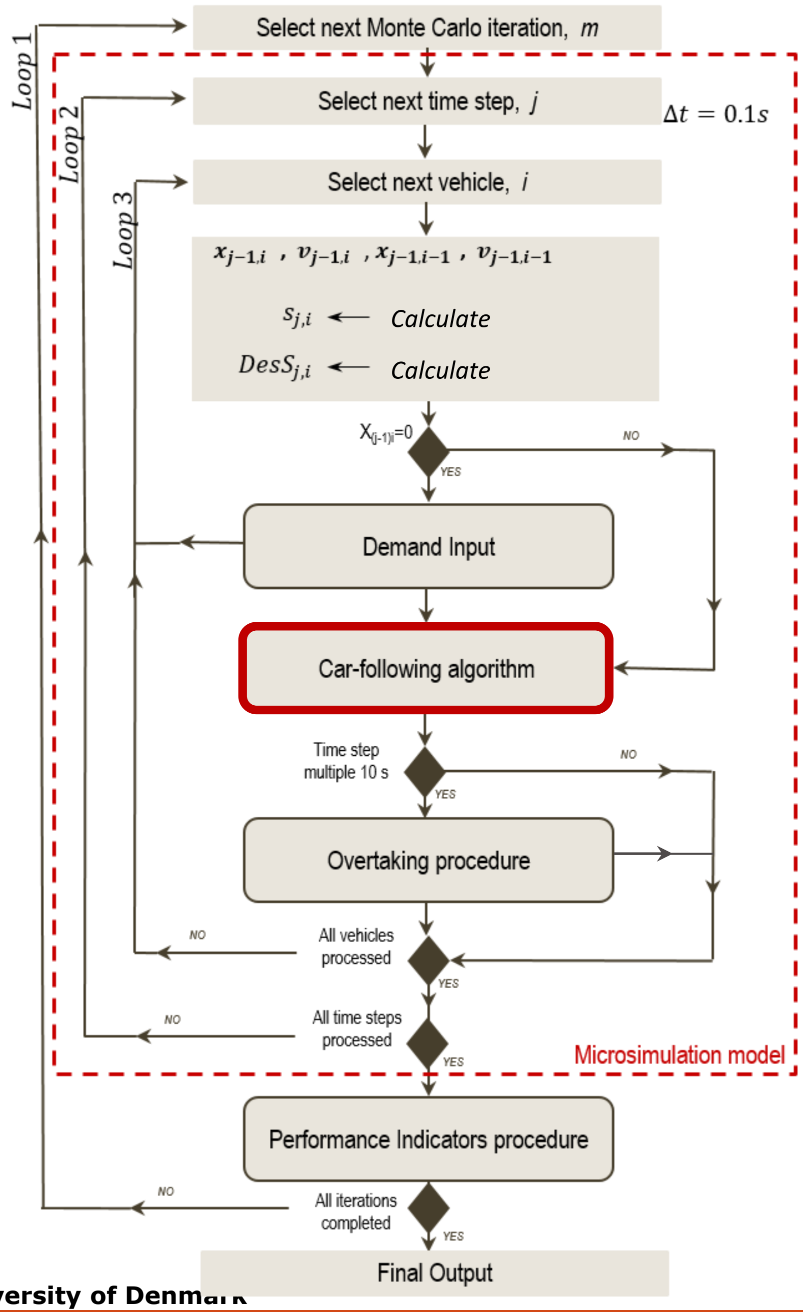
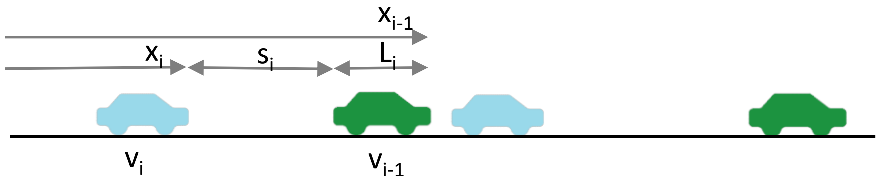
Simulation Framework





CAR FOLLOWING ALGORITHM

IIDM

$$z_{ji} = \frac{DesS(v_{(j-1)i}, \Delta v_{(j-1)i})}{s_{(j-r_i)i}}$$

- if $v \leq v_0$

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- if $v > v_0$

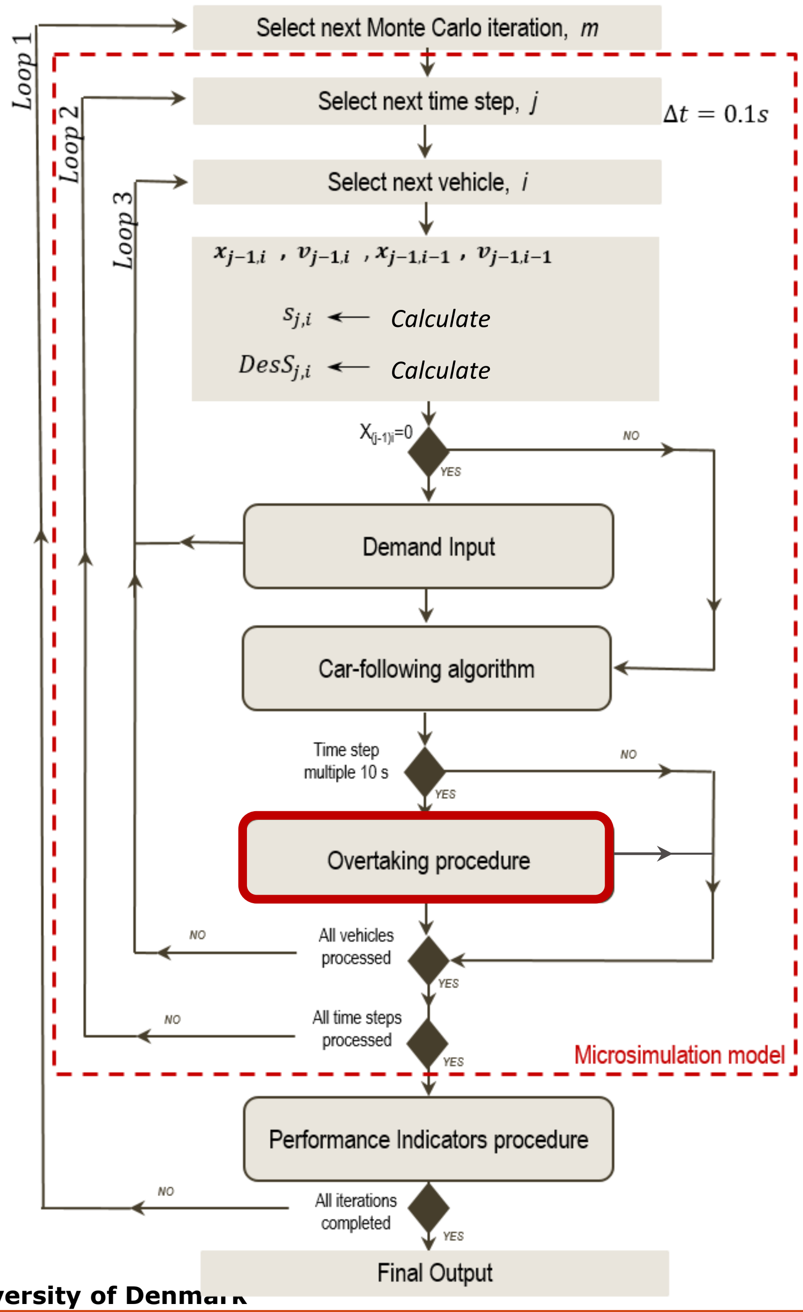
$$a_{free_{ji}} = -B \cdot \left[1 - \left(\frac{v_{0i}}{v_{(j-r_i)i}}\right)^{A \cdot \delta / B}\right], \quad a_{ji} = \begin{cases} a_{free_{ji}} + A \cdot \left[1 - z_{ji}^2\right] & z_{ji} \geq 1 \\ a_{free_{ji}} & z_{ji} < 1 \end{cases}$$

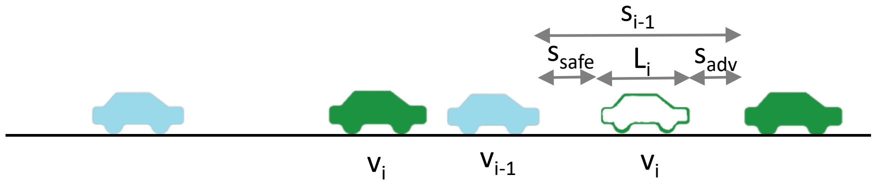
Update equations:

$$v_{j,i} = v_{j-1,i} + a_{j,i}(\Delta t)$$

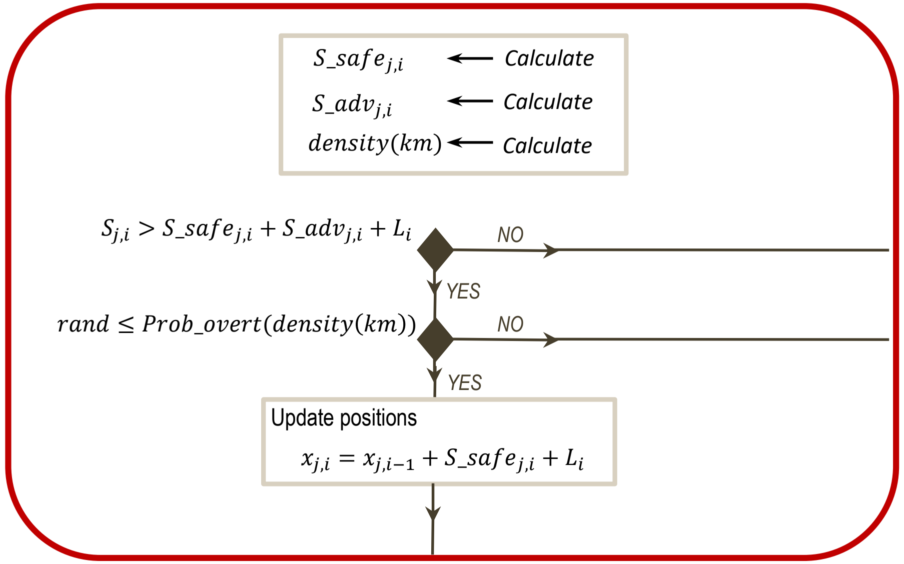
$$x_{j,i} = x_{j-1,i} + v_{j,i}(\Delta t) + \frac{1}{2} a_{j,i} (\Delta t)^2$$

Simulation Framework

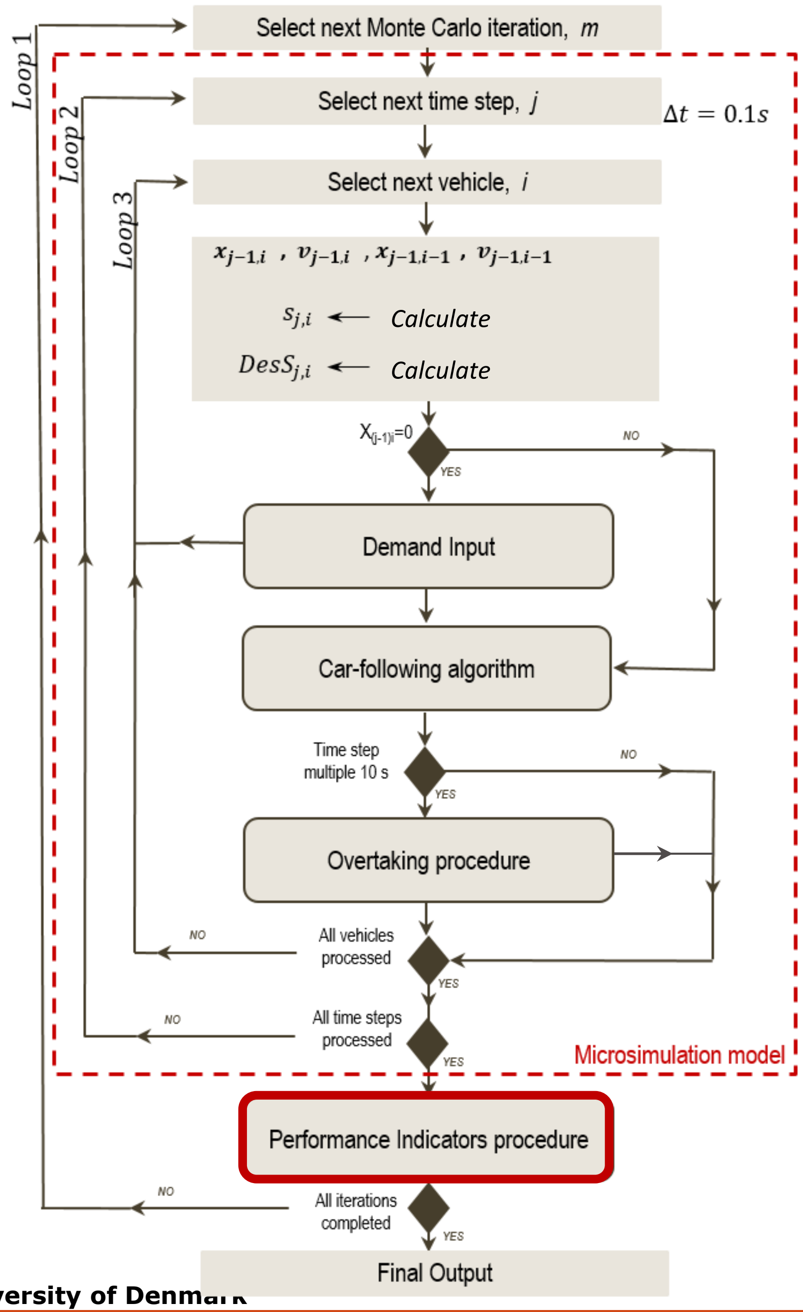


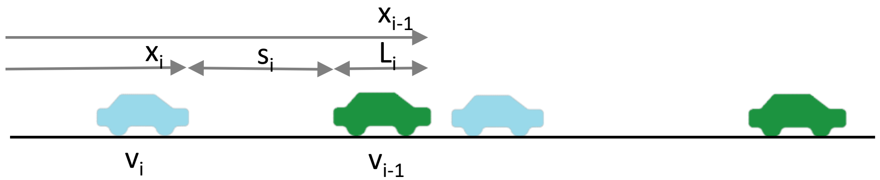


OVERTAKING PROCEDURE



Simulation Framework





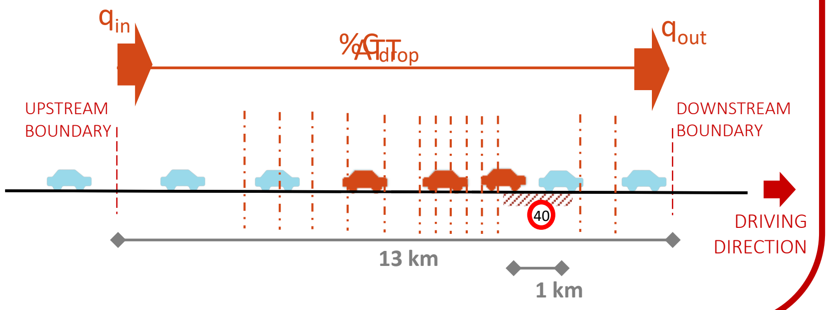
PERFORMANCE INDICATORS

AVERAGE TRAVEL TIME (ATT)

THROUGHPUT AND CAPACITY: Inflow, Outflow, Capacity drop

QUEUE: upstream vehicles with v<40km/h

DETECTORS: Speed, Flow, Density, Spacing



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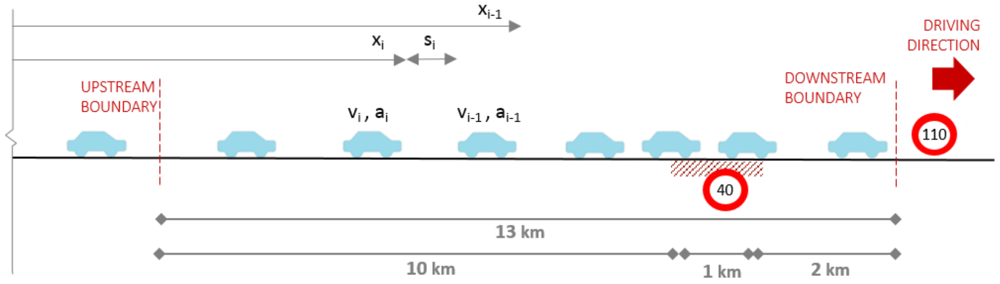
Case Study: scenario analysis

Validation of Base Scenario: 0% AV

Analysis of AVs T and v_0 parameter sensitivity

Analysis of AVs at different penetration rates



Cars

Performance Indicators:

- Av. Travel time
- Throughput
- Capacity drop
- Queue

Stochastic IIDM

$A = 3\ m/s^2$

$B = 1.67\ m/s^2$

$B_{max} = 7.5\ m/s^2$

$S_0 = 2\ m$

$T = 1.5\ s$

$\delta = 4$

$v_0 = norm(30.56;3.5^2)\ m/s$

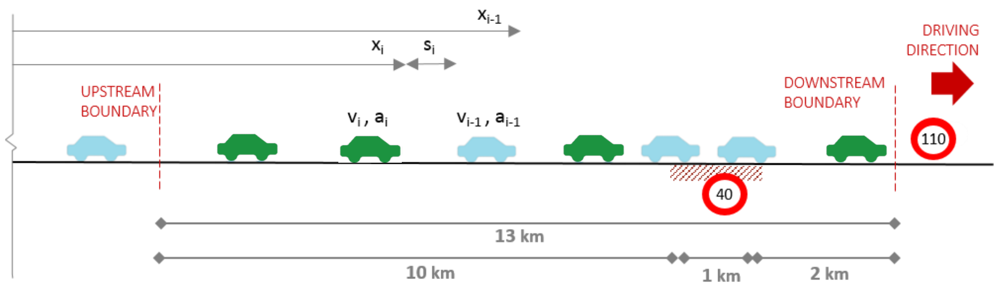
$r_i = norm(0.5;0.1^2)\ s$

Case Study: AVs different driving behaviours

Validation of Base Scenario: 0% AV

Analysis of AVs T and v_0 parameter sensitivity

Analysis of AVs at different penetration rates



	v_0	T
50% AVs	80 km/h	1.0 s
	110 km/h	1.0 s
	145 km/h	1.0 s
50% AVs	110 km/h	0.5 s
	110 km/h	1.0 s
	110 km/h	1.3 s

Performance Indicators:

- Av. Travel time
- Throughput
- Capacity drop
- Queue

Cars

Stochastic IIDM

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AVs

Deterministic IIDM

$A = 3\ m/s^2$

$B = 1.67\ m/s^2$

$B_{max} = 7.5\ m/s^2$

$S_0 = 2\ m$

T = 1 s

$\delta = 4$

$\mathbf{v_0}$ = 30.56 m/s =110km/h

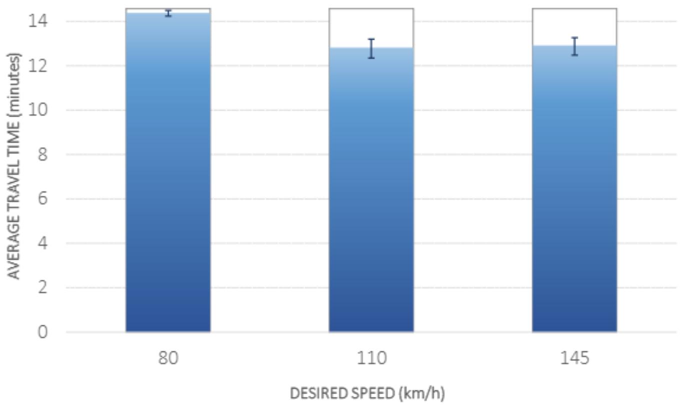
$r_i = 0\ s$

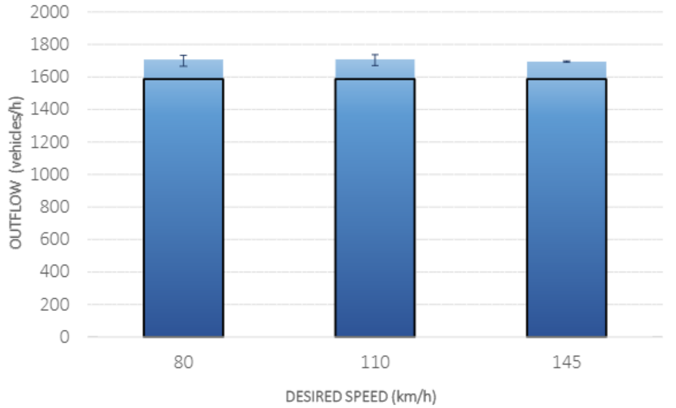
Case Study: AVs different driving behaviour – 50% AVs

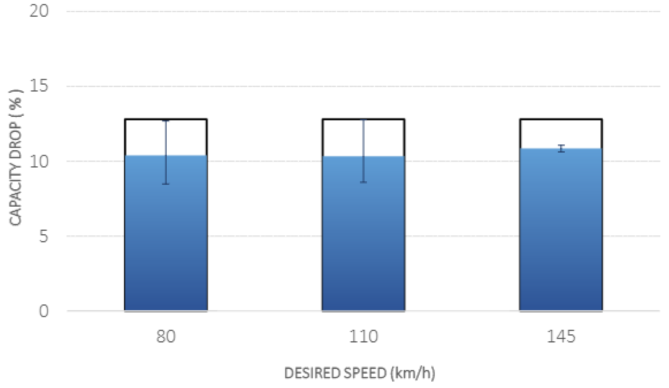
ATT = Average travel time

q_{out} = Outflow

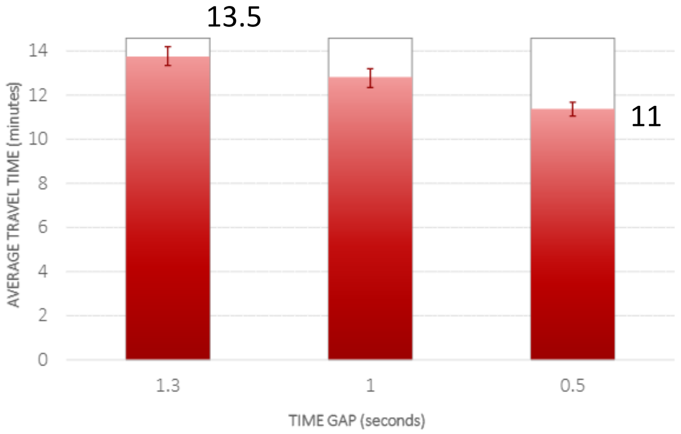
$\%C_{drop}$ = Capacity drop

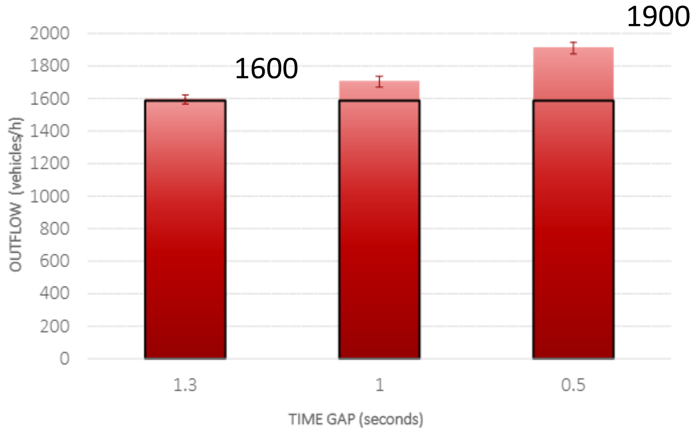


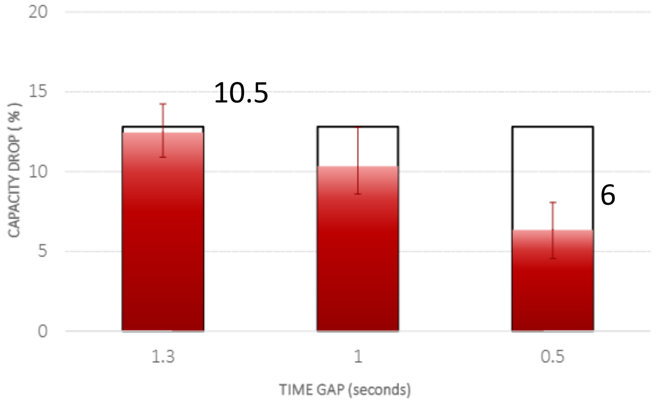




v_0 = Desired speed, parameter sensitivity







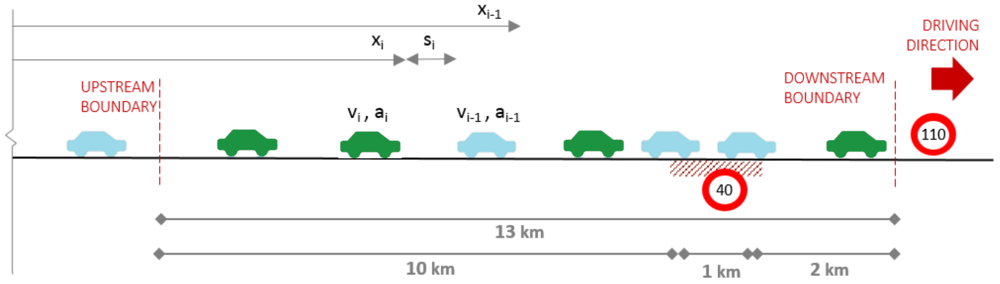
T = Speed dependent time gap, parameter sensitivity

Case Study: AVs at different penetration rates

Validation of Base Scenario: 0% AV

Analysis of AVs T and v_0 parameter sensitivity

Analysis of AVs at different penetration rates



% AVs	v_0	T
0	110 km/h	1.0 s
25	110 km/h	1.0 s
50	110 km/h	1.0 s
75	110 km/h	1.0 s
90	110 km/h	1.0 s
100	110 km/h	1.0 s

Performance Indicators:

- Av. Travel time
- Throughput
- Capacity drop
- Queue

Cars

Stochastic IIDM

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AVs

Deterministic IIDM

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$B = 1.67\ m/s^2$

$B_{max} = 7.5\ m/s^2$

$S_0 = 2\ m$

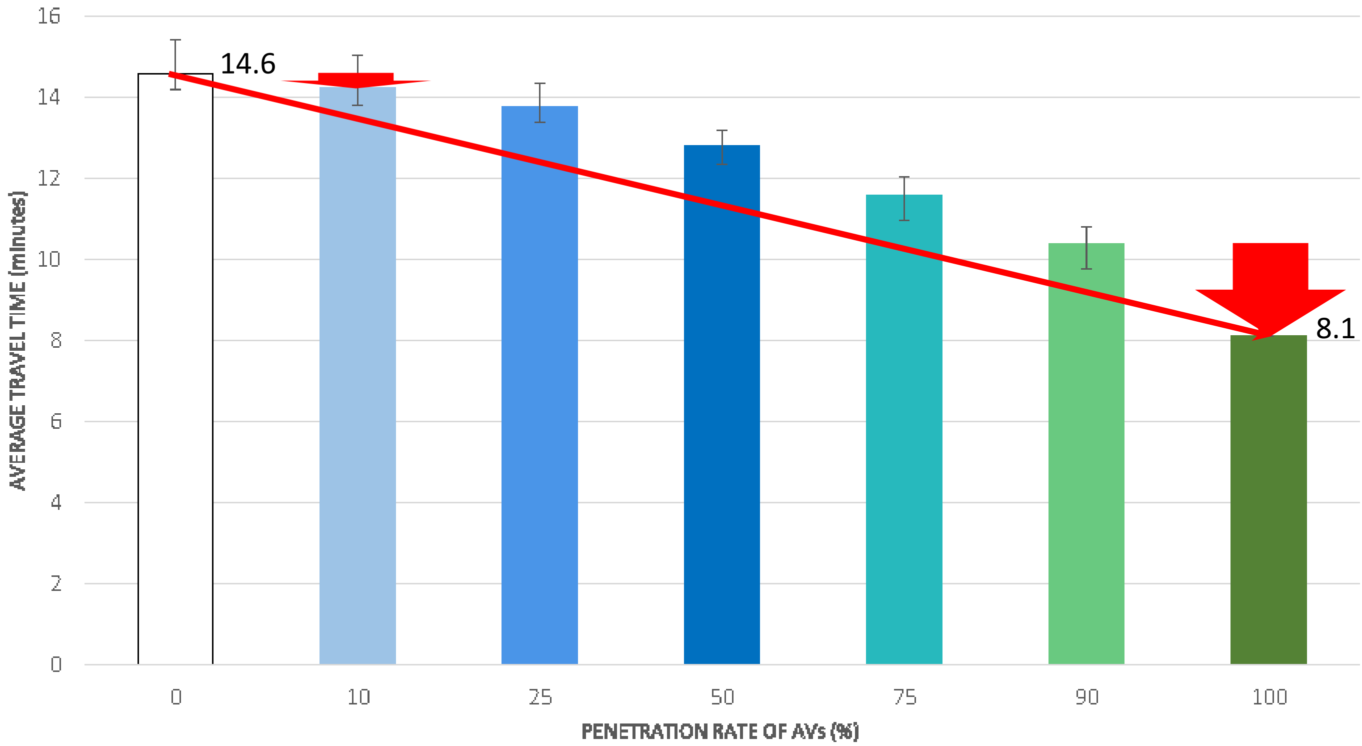
$\mathbf{T} = 1\ s$

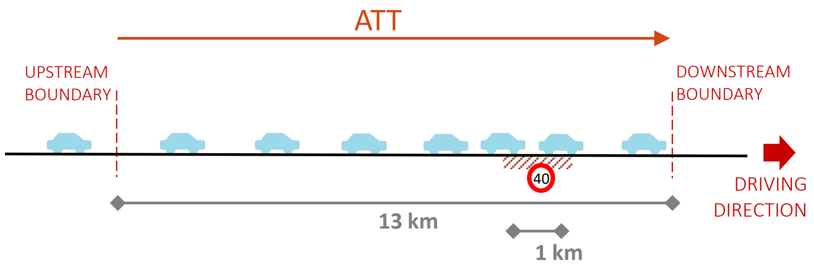
$\delta = 4$

$\mathbf{v_0} = 30.56\ m/s = 110 km/h$

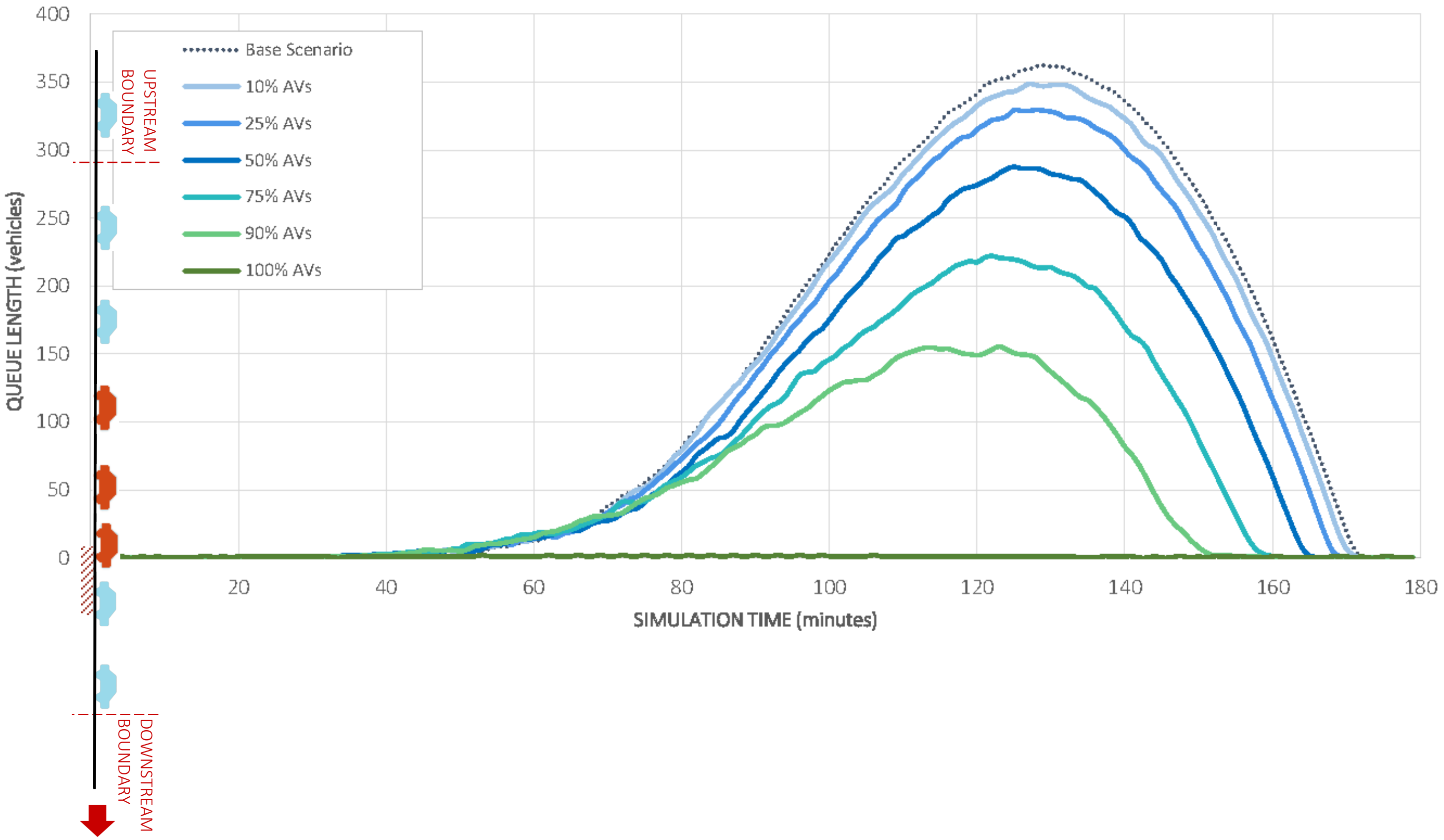
$r_i = 0\ s$

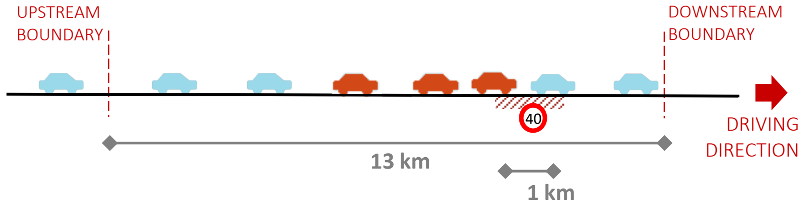
AVs at different penetration rates – AVERAGE TRAVEL TIME



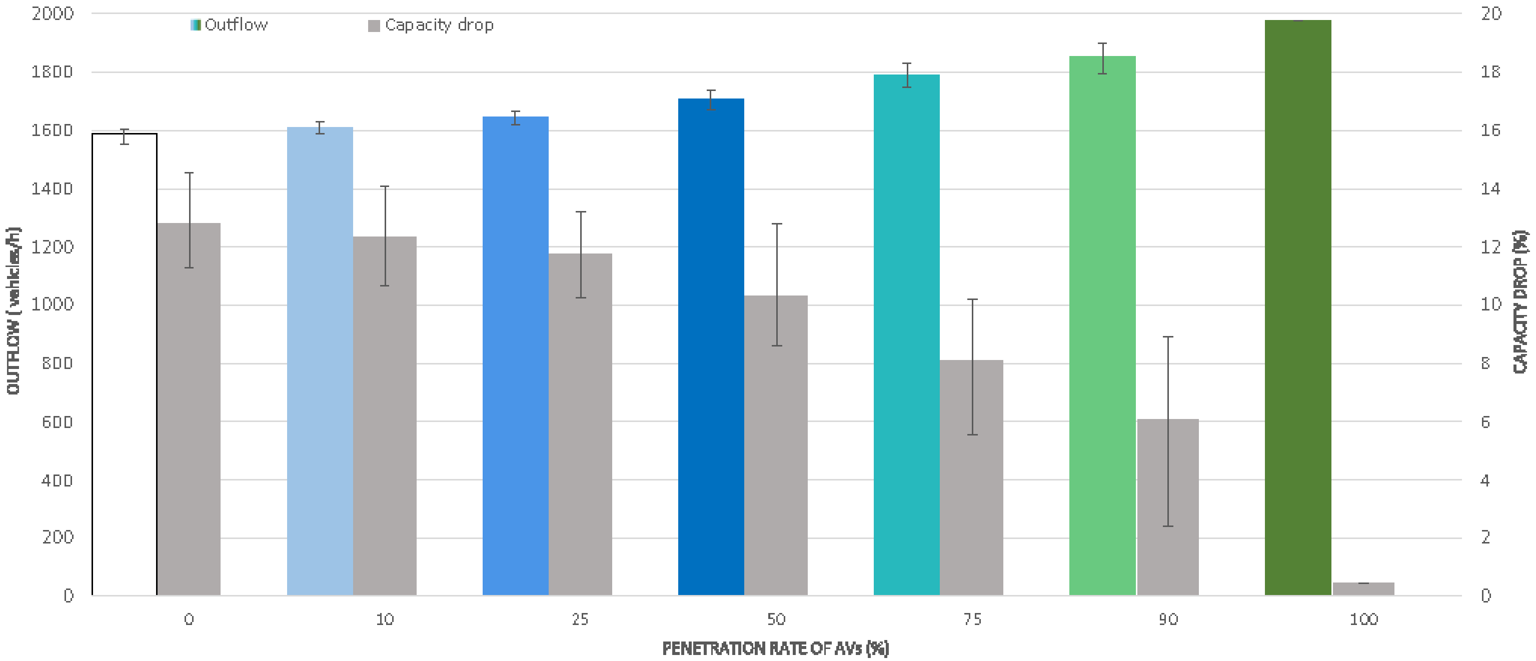


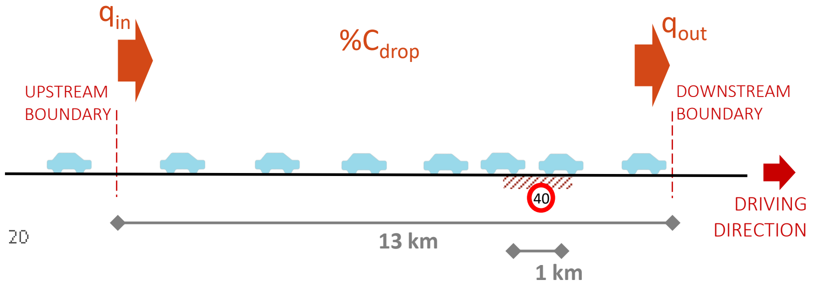
AVs at different penetration rates – QUEUE





AVs at different penetration rates – THROUGHPUT AND CAPACITY



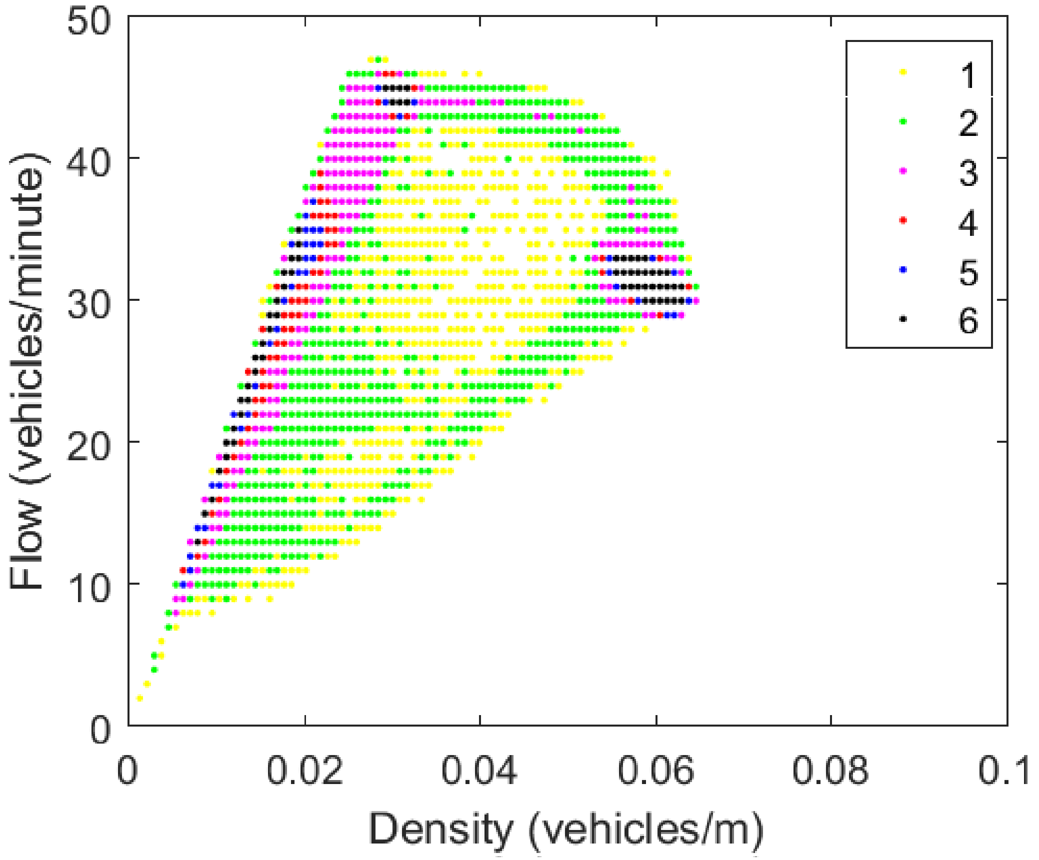


$$\%Cdrop = \frac{(q_{in} - q_{out})}{q_{in}} . 100$$

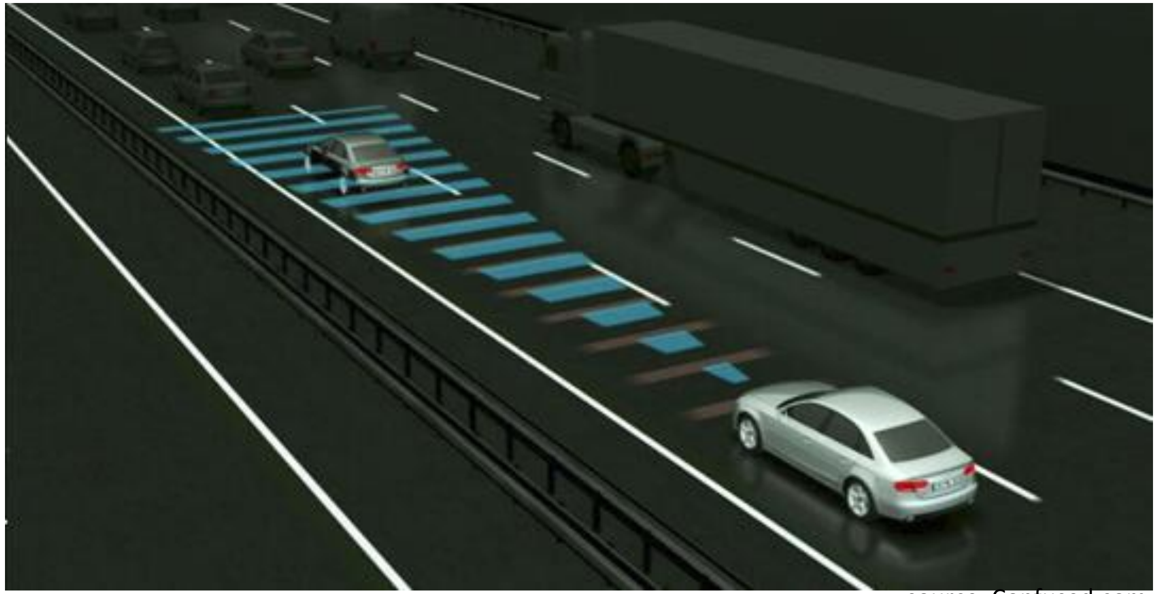
AVs at different penetration rates – MFD

Flow – Density

90% AVs

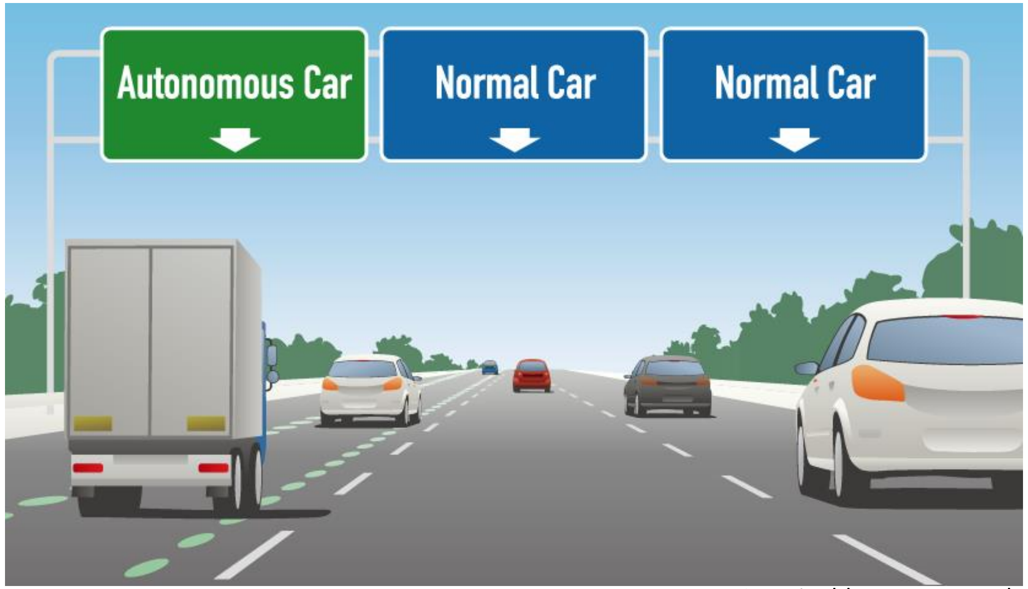


How / What should we plan?



source: Confused.com

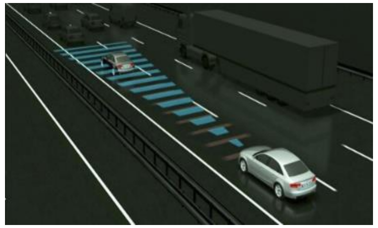
AVS IN MOTORWAYS MIXED IN TRAFFIC



source: Sustainable Transport Lab

DEDICATED LANES FOR AVS IN MOTORWAYS

AVs at different penetration rates – Benefit calculations

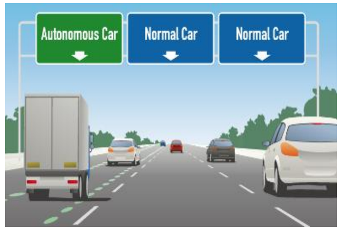


AVS IN MOTORWAYS MIXED IN TRAFFIC

NORMAL CARS + AVs	33.3%
NORMAL CARS + AVs	33.3%
NORMAL CARS+ AVs	33.3%

$$Total\ Benefits = 5.5 + 5.5 + 5.5$$

$$Total\ Benefits = \mathbf{16.5\ Mdkk/year}$$



DEDICATED LANES FOR AVS IN MOTORWAYS

AVs	100%
NORMAL CARS	0%
NORMAL CARS	0%

$$Total\ Benefits = 35.2 + 0 + 0$$

$$Total\ Benefits = \mathbf{35.2\ Mdkk/year}$$

- Scaling of results:
  - 2 peak periods per day
  - 1 year (285 days)

Penetration rate of AVs %	Total benefits M dkk / lane / year
0	-
10	1.6
25	4.2
33.3	5.5
50	9.2
75	15.9
90	22.5
100	35.2

Conclusions

- The potential network benefits do not follow a linear relation to the market penetration rate of AVs.

	Potential Benefits with respect to current situation (%)	
Penetration rate of AVs	**Time saving**	**Capacity increase**
50%	12	6
75%	20	12
100%	45	25

- Benefits at low market shares could be difficult to perceive.

- At early implementation stages beneficial to plan towards motorways with dedicated lanes for AVs rather than AVs mixed in traffic. However, several practical problems could arise when implementing into real-world.

- Work is limited to analyze changes in vehicle dynamics and does not consider potential induced demand.

THANK YOU FOR LISTENING

Andrea Papu Carrone
Jeppe Rich

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